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ORIGINAL INVESTIGATIONS

# Outcomes in Transcatheter Aortic Valve Replacement for Bicuspid Versus Tricuspid Aortic Valve Stenosis



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## ABSTRACT

**BACKGROUND** Transcatheter aortic valve replacement (TAVR) is being increasingly performed in patients with bicuspid aortic valve stenosis (AS).

**OBJECTIVES** This study sought to compare the procedural and clinical outcomes in patients with bicuspid versus tricuspid AS from the Bicuspid AS TAVR multicenter registry.

**METHODS** Outcomes of 561 patients with bicuspid AS and 4,546 patients with tricuspid AS were compared after propensity score matching, assembling 546 pairs of patients with similar baseline characteristics. Procedural and clinical outcomes were recorded according to Valve Academic Research Consortium-2 criteria.

**RESULTS** Compared with patients with tricuspid AS, patients with bicuspid AS had more frequent conversion to surgery (2.0% vs. 0.2%;  $p = 0.006$ ) and a significantly lower device success rate (85.3% vs. 91.4%;  $p = 0.002$ ). Early-generation devices were implanted in 320 patients with bicuspid and 321 patients with tricuspid AS, whereas new-generation devices were implanted in 226 and 225 patients with bicuspid and tricuspid AS, respectively. Within the group receiving early-generation devices, bicuspid AS had more frequent aortic root injury (4.5% vs. 0.0%;  $p = 0.015$ ) when receiving the balloon-expanding device, and moderate-to-severe paravalvular leak (19.4% vs. 10.5%;  $p = 0.02$ ) when receiving the self-expanding device. Among patients with new-generation devices, however, procedural results were comparable across different prostheses. The cumulative all-cause mortality rates at 2 years were comparable between bicuspid and tricuspid AS (17.2% vs. 19.4%;  $p = 0.28$ ).

**CONCLUSIONS** Compared with tricuspid AS, TAVR in bicuspid AS was associated with a similar prognosis, but lower device success rate. Procedural differences were observed in patients treated with the early-generation devices, whereas no differences were observed with the new-generation devices. (J Am Coll Cardiol 2017;69:2579–89) © 2017 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).



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## ABBREVIATIONS AND ACRONYMS

**AS** = aortic valve stenosis

**CI** = confidence interval

**OR** = odds ratio

**TAVR** = transcatheter aortic  
valve replacement

**T**ranscatheter aortic valve replacement (TAVR) has evolved from a novel technology to an established therapy for high-risk patients with symptomatic severe aortic valve stenosis (AS). Numerous studies have demonstrated the safety and efficacy of TAVR, and more than 250,000 patients have been treated with this technology (1–6). Although randomized trials have established TAVR as the standard treatment in inoperable patients and a reasonable option in high

surgical-risk patients, these trials excluded congenital bicuspid AS due to its unique morphological features (1,2,5–7).

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The experience of TAVR in bicuspid AS is limited to small series (8–12). Based on data from previous registries, the proportion of patients with bicuspid AS may reach 2% to 6% (13,14). Previous studies were limited by the clear baseline differences in age and comorbidities favoring the bicuspid AS study group

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compared with the tricuspid AS study group. However, there is a paucity of data comparing the clinical outcomes of TAVR in bicuspid and tricuspid AS. Given the increasing frequency of bicuspid AS in younger patients, coupled with the worldwide shift toward treating younger and lower surgical-risk patients with TAVR, the clinical outcomes of TAVR in bicuspid AS warrant special attention (6,15,16). Furthermore, current TAVR practice is largely based on evidence on TAVR for tricuspid AS, and thus, understanding the differences in clinical outcomes of TAVR in bicuspid and tricuspid AS is meaningful. Therefore, we aim to evaluate the clinical outcomes of TAVR in bicuspid AS and compare them to tricuspid AS. In addition, the differences in outcomes between bicuspid versus tricuspid AS will be analyzed, taking into consideration the technological developments in transcatheter valves.

## METHODS

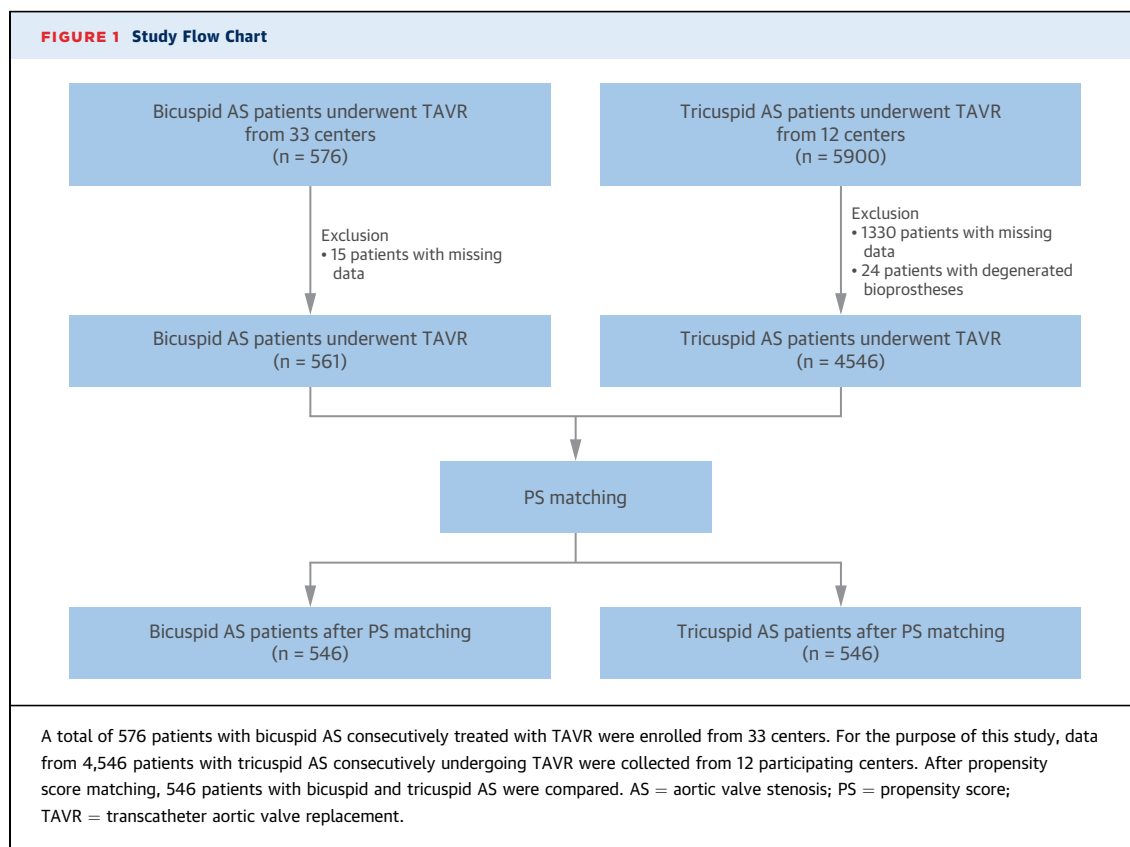
**STUDY DESIGN AND PATIENT POPULATION.** The Bicuspid AS TAVR registry is an international, multicenter, observational study that enrolled all consecutive patients with bicuspid AS undergoing TAVR. The registry was initiated in December 2013, and a total of 33 centers from Europe, North America, and the Asia-Pacific region contributed to the registry. We collected data retrospectively for cases performed before initiation, and prospectively thereafter. All inconsistencies were resolved directly with local investigators and on-site data monitoring. For the purpose of this study, data for all consecutive patients with tricuspid AS treated with TAVR during the same period were collected from 12 participating centers, and procedural and clinical outcomes of patients with bicuspid and tricuspid AS were compared. As a secondary analysis, the outcomes of TAVR in bicuspid AS were compared with those with tricuspid AS according to device type. This study was approved by the institutional review board of each institution, and all patients provided written informed consent for TAVR and the use of anonymous clinical, procedural, and follow-up data for research. For a retrospective analysis of clinically acquired and anonymized data, the institutional review boards of some institutions waived the need for written patient informed consent.

**BICUSPID AORTIC VALVE.** Bicuspid aortic valve morphology was classified as previously described by Sievers and Schmidtke (15) according to the number of cusps and the presence of raphe, as well as spatial position and symmetry of raphe and cusps. Type 0 was assigned to morphologies

characterized by the presence of 2 symmetric cusps and 1 commissure without evidence of a raphe. Type 1 was assigned to valve morphologies with 1 raphe, and type 2 when 2 raphe were present. All participating centers reviewed and subsequently confirmed the diagnosis and classification of bicuspid AS. When both transesophageal echocardiography and preprocedural computed tomography were performed, patients were excluded if the diagnosis of bicuspid aortic valve was not consistent or remained speculative.

**STUDY DEVICES AND PROCEDURE.** Patients were selected for TAVR at the institutional level after discussions by the multidisciplinary heart team. The access site was determined by the multidisciplinary heart team. All centers adopted a transfemoral-first approach policy, with criteria for performing a non-transfemoral approach based on the heart team's consideration of the size, calcification, and atheroma of the aorto-iliofemoral artery. Device sizes were selected based on 3-dimensional, multidetector-row computed tomography-based annular measurements or transesophageal echocardiogram assessment. All TAVR procedures were conducted in accordance with local guidelines using standard techniques via transfemoral, transapical, trans-subclavian, or transaortic access, and the early-generation devices (the Sapien XT [Edwards Lifesciences, Irvine, California] and CoreValve [Medtronic, Minneapolis, Minnesota]) or new-generation devices (the Sapien 3 [Edwards Lifesciences], Lotus [Boston Scientific, Natick, Massachusetts] and Evolut R [Medtronic]) were implanted (17-22).

**ENDPOINTS AND DEFINITIONS.** The primary endpoint of the present study was all-cause mortality at 1 and 2 years. Secondary endpoints were 30-day major clinical endpoints using the Valve Academic Research Consortium (VARC)-2 criteria (23). Device success was defined as a composite endpoint including: 1) absence of procedure-related death; 2) correct positioning of a single prosthetic heart valve into the proper anatomic location; and 3) intended performance of the prosthetic heart valve (no prosthesis-patient mismatch, mean aortic gradient <20 mm Hg or peak velocity <3 m/s, and no moderate or severe paravalvular leak). Other endpoints included new permanent pacemaker insertion, procedure- and device-related complications, and echocardiographic assessment of the valve and cardiac function at discharge. No echocardiographic core laboratory was used, and all echocardiographic data were site-reported. The severity of regurgitation was qualitatively assessed and graded using



transthoracic echocardiography at each institution, according to established guidelines (23).

**DATA COLLECTION.** Data collection by a dedicated case report form included baseline clinical, laboratory, echocardiographic, and computed tomographic data, as well as procedural data and clinical follow-up data at pre-specified time points (1, 6, and 12 months, and yearly thereafter). Follow-up was obtained by clinical visits and/or through telephone contacts. Referring cardiologists, general practitioners, and patients were contacted whenever necessary for further information. All data provided by each institution were anonymized, centrally collected, and assessed for quality.

**STATISTICAL ANALYSIS.** Given the differences in baseline clinical, echocardiographic, and procedural characteristics between patients with bicuspid and tricuspid AS, propensity score matching was applied to identify a cohort of patients with similar baseline characteristics, and thus, clinical outcomes of propensity score-matched cohorts were compared. The propensity score is a conditional probability of having a particular exposure (bicuspid AS or tricuspid AS), given a set of covariates measured at baseline. The

propensity score has been developed using a logistic regression model according to a nonparsimonious approach, and all clinical variables (age, sex, New York Heart Association functional class III or IV, hypertension, diabetes mellitus, creatinine, peripheral vascular disease, prior cerebrovascular accident, chronic lung disease, prior percutaneous coronary intervention, prior coronary artery bypass graft, mean gradient, and left ventricular ejection fraction) as well as procedural data (transfemoral access and device type) were included in the analysis. Additionally, we created propensity score-matched cohorts for subgroups (early- and new-generation devices), and outcomes were compared. The details of the propensity score method are described in the [Online Appendix](#).

After matching, continuous variables following a normal distribution were compared using the paired-sample Student *t* test; otherwise, the Wilcoxon rank sum test was used. Differences for matched categorical variables were analyzed with McNemar's test. For the VARC-2 major endpoints and other complications, frequencies and relative numbers were given including the odds ratio (OR) with 95% confidence intervals (CIs) and *p* values of

McNemar's test for the propensity score-matched cohorts or the chi-square test for the subgroup analysis. Cumulative survival rates were analyzed using the Kaplan-Meier method, and were compared using win ratio tests for the propensity score-matched cohort and log-rank test for the subgroup analysis (24). All statistical analyses were performed using SPSS software version 21.0 (SPSS, Inc., Chicago, Illinois) and R software version 2.12.2 (25). A 2-sided *p* value <0.05 was considered to indicate statistical significance.

## RESULTS

**BASELINE CHARACTERISTICS.** A total of 576 patients with bicuspid AS were treated with TAVR across 33 participating centers between April 2005 and May 2016. During the same period, a total of 5,900 patients with tricuspid AS were treated with TAVR across 12 participating centers. Patients with missing data or those who received TAVR for degenerated bioprostheses were excluded from the analysis. Consequently, 561 patients with bicuspid AS and 4,546 patients with tricuspid AS were included in the present analysis (Figure 1). The type of bicuspid AS was diagnosed in 497 patients (88.6%): type 0 was diagnosed in 63 patients (12.7%), type 1 in 426 (85.7%), and type 2 in 8 (1.6%).

In the unadjusted cohort, patients with bicuspid AS were younger and more likely to be male, whereas patients with tricuspid AS were more likely to have multiple comorbidities (Online Table 1). In terms of surgical risk, patients with bicuspid AS had a lower Logistic European System for Cardiac Operative Risk Evaluation (EuroSCORE) ( $14.8 \pm 12.3\%$  vs.  $16.7 \pm 11.8\%$ ; *p* = 0.003) and Society of Thoracic Surgeons (STS) score ( $5.0 \pm 5.1\%$  vs.  $6.5 \pm 8.8\%$ ; *p* < 0.001). Furthermore, large prostheses were used more often in the bicuspid AS group (34.5% vs. 14.5%; *p* < 0.001), whereas the transfemoral approach was equally frequent in both groups. After performing propensity score matching, both groups were well matched, with no significant differences in baseline characteristics, except more frequent use of the largest prostheses in the bicuspid AS group (Table 1).

**PROCEDURAL AND CLINICAL OUTCOMES.** Table 2 summarizes the procedural and clinical outcomes of the propensity score-matched cohort. Compared with patients with tricuspid AS, patients with bicuspid AS had more frequent conversion to surgery, implantation of second valve, and moderate or severe paravalvular leak, as well as a lower device success rate. There was no significant difference in new

**TABLE 1** Baseline Characteristics

	Propensity Score Matched Cohort		
	Bicuspid AS (n = 546)	Tricuspid AS (n = 546)	p Value
Age, yrs	77.2 ± 8.2	77.2 ± 8.8	0.91
Male	343 (62.8)	331 (60.6)	0.48
NYHA functional class III or IV	439 (80.4)	428 (82.1)	0.48
Logistic EuroSCORE, %	16.1 ± 12.0	16.9 ± 13.9	0.58
STS score, %	4.6 ± 4.6	4.3 ± 3.0	0.29
Hypertension	382 (70.0)	385 (70.5)	0.89
Diabetes mellitus	128 (23.4)	127 (23.3)	>0.99
Creatinine, mg/dl	1.2 ± 0.9	1.2 ± 0.7	0.81
Peripheral vascular disease	83 (15.2)	85 (15.6)	0.93
Prior cerebrovascular accident	77 (14.1)	69 (12.6)	0.53
Chronic lung disease	98 (17.9)	82 (15.0)	0.23
Prior PCI	121 (22.2)	128 (23.4)	0.66
Prior CABG	62 (11.4)	67 (12.3)	0.70
Echocardiographic findings			
Mean gradient, mm Hg	49.7 ± 17.7	48.5 ± 17.1	0.25
Aortic valve area, cm <sup>2</sup>	0.7 ± 0.2	0.7 ± 0.2	0.86
LVEF, %	51.6 ± 15.0	51.6 ± 15.2	0.99
Procedural data			
Transfemoral access	432 (85.9)	430 (86.2)	0.93
Device			
Early-generation devices	320 (58.6)	321 (58.8)	>0.99
Sapien XT	155 (28.4)	150 (27.5)	0.77
CoreValve	165 (30.2)	171 (31.3)	0.73
New-generation devices	226 (41.4)	225 (41.2)	>0.99
Sapien 3	160 (29.3)	162 (29.7)	0.94
Lotus	43 (7.9)	47 (8.6)	0.73
Evolut R	23 (4.2)	16 (2.9)	0.32
Size*			
Small	105/503 (20.9)	152/499 (30.5)	0.001
Medium	226/503 (44.9)	238/499 (47.7)	0.38
Large	172/503 (34.2)	109/499 (21.8)	<0.001
Type of bicuspid			
Determined	478 (87.5)	—	
Type 0	61 (12.8)	—	
Type 1	409 (85.6)	—	
Type 2	8 (1.7)	—	
Undetermined/unavailable	68 (12.5)	—	

Values are mean ± SD, n (%), or n/N (%). \*Small = 23 mm for Sapien XT/Sapien 3 and ≤26 mm for CoreValve/Evolut R; medium = 26 mm for Sapien XT/Sapien 3 and 29 mm for CoreValve/Evolut R; large = 29 mm for Sapien XT/Sapien 3, 31 mm for CoreValve, and 34 mm for Evolut R.

AS = aortic valve stenosis; CABG = coronary artery bypass graft; EuroSCORE = European System for Cardiac Operative Risk Evaluation; LVEF = left ventricular ejection fraction; NYHA = New York Heart Association; PCI = percutaneous coronary intervention; STS = Society of Thoracic Surgeons.

permanent pacemaker insertion between the bicuspid and tricuspid AS groups.

In terms of 30-day clinical outcomes, there were no significant differences between the bicuspid



TABLE 2 Procedural and Clinical Outcomes				
	Propensity Score Matched Cohort			
	Bicuspid AS (n = 546)	Tricuspid AS (n = 546)	p Value	OR (95% CI)
Procedural outcomes				
Procedure-related death	7 (1.3)	6 (1.1)	>0.99	1.17 (0.39-3.47)
Conversion to surgery	11 (2.0)	1 (0.2)	0.006	11.00 (1.42-85.20)
Coronary obstruction	5 (0.9)	3 (0.5)	0.73	1.67 (0.40-6.97)
Aortic root injury	9 (1.6)	0 (0.0)	0.004	—
Implantation of 2 valves	26 (4.8)	8 (1.5)	0.002	3.71 (1.61-8.56)
New permanent pacemaker	84 (15.4)	84 (15.4)	>0.99	1.00 (0.72-1.39)
Echocardiographic findings				
Mean gradient, mm Hg	10.8 ± 6.7	10.2 ± 4.4	0.18	
LVEF, %	54.2 ± 13.6	54.7 ± 13.9	0.79	
Moderate or severe paravalvular leak	57 (10.4)	37 (6.8)	0.04	1.61 (1.04-2.48)
Device success	466 (85.3)	499 (91.4)	0.002	0.54 (0.37-0.80)
30-day outcomes				
All-cause mortality	20 (3.7)	18 (3.3)	0.87	1.11 (0.59-2.10)
Stroke	16 (2.9)	10 (1.8)	0.33	1.60 (0.73-3.53)
Nondisabling	7 (1.3)	6 (1.1)	>0.99	1.17 (0.39-3.47)
Disabling	9 (1.6)	4 (0.7)	0.27	2.25 (0.69-7.31)
Bleeding				
Major	20 (3.7)	22 (4.0)	0.88	0.91 (0.50-1.67)
Life-threatening	11 (2.0)	19 (3.5)	0.20	0.58 (0.28-1.22)
Major vascular complication	16 (2.9)	16 (2.9)	>0.99	1.00 (0.50-2.00)
Acute kidney injury (stage 2 or 3)	11 (2.0)	5 (0.9)	0.21	2.20 (0.77-6.33)
Values are n (%) or mean ± SD, unless otherwise indicated. CI = confidence interval; OR = odds ratio; other abbreviations as in Table 1.				

and tricuspid AS groups in 30-day all-cause mortality, stroke, life-threatening bleeding, major vascular complications, and stage 2 or 3 acute kidney injury.

**Outcomes according to device type.** When stratified according to whether they received early- versus new-generation devices, patients with bicuspid AS had more frequent procedural complications than those with tricuspid AS when receiving the early-generation devices (conversion to surgery: 2.5% vs. 0.3%;  $p = 0.02$ ; second valve implantation: 7.2% vs. 2.2%;  $p = 0.003$ ; moderate or severe paravalvular leak: 15.9% vs. 10.3%;  $p = 0.03$ ) (Figure 2A). However, there were no significant differences in procedural complications between the bicuspid and tricuspid AS groups when receiving the new-generation devices (Figure 2B). These findings were consistently observed in propensity score matched cohorts for early- and new-generation devices (Online Figure 1).

Procedural and clinical outcomes according to device type are shown in Online Figure 2. Compared with patients with tricuspid AS, patients with bicuspid AS had more frequent aortic root injury (4.5% vs. 0.0%;  $p = 0.015$ ) when receiving the Sapien

XT. In addition, patients with bicuspid AS had more frequent second valve implantation (11.6% vs. 2.9%;  $p = 0.002$ ), moderate or severe paravalvular leak (19.4% vs. 10.5%;  $p = 0.02$ ), and subsequent lower device success rate (72.1% vs. 86.0%;  $p = 0.002$ ) than those with tricuspid AS when receiving the CoreValve. However, there were no significant differences in these adverse procedural events between groups when receiving the Sapien 3 and Lotus.

There were no significant differences in 30-day mortality and other major clinical endpoints between groups, except that patients with bicuspid AS had a higher rate of major vascular complications compared with patients with tricuspid AS when receiving the Sapien XT (5.8% vs. 0.7%;  $p = 0.01$ ) (Online Figures 3 to 5).

In terms of outcomes across bicuspid phenotype, there were no significant differences in procedural and clinical outcomes between type 0 and type 1 bicuspid AS (Online Table 2). Of note, moderate or severe paravalvular leak occurred in 5 patients (8.2%) for type 0 bicuspid AS and 44 patients (10.8%) for type 1 bicuspid AS ( $p = 0.54$ ), whereas all aortic root injury occurred only in patients with type 1 bicuspid AS.

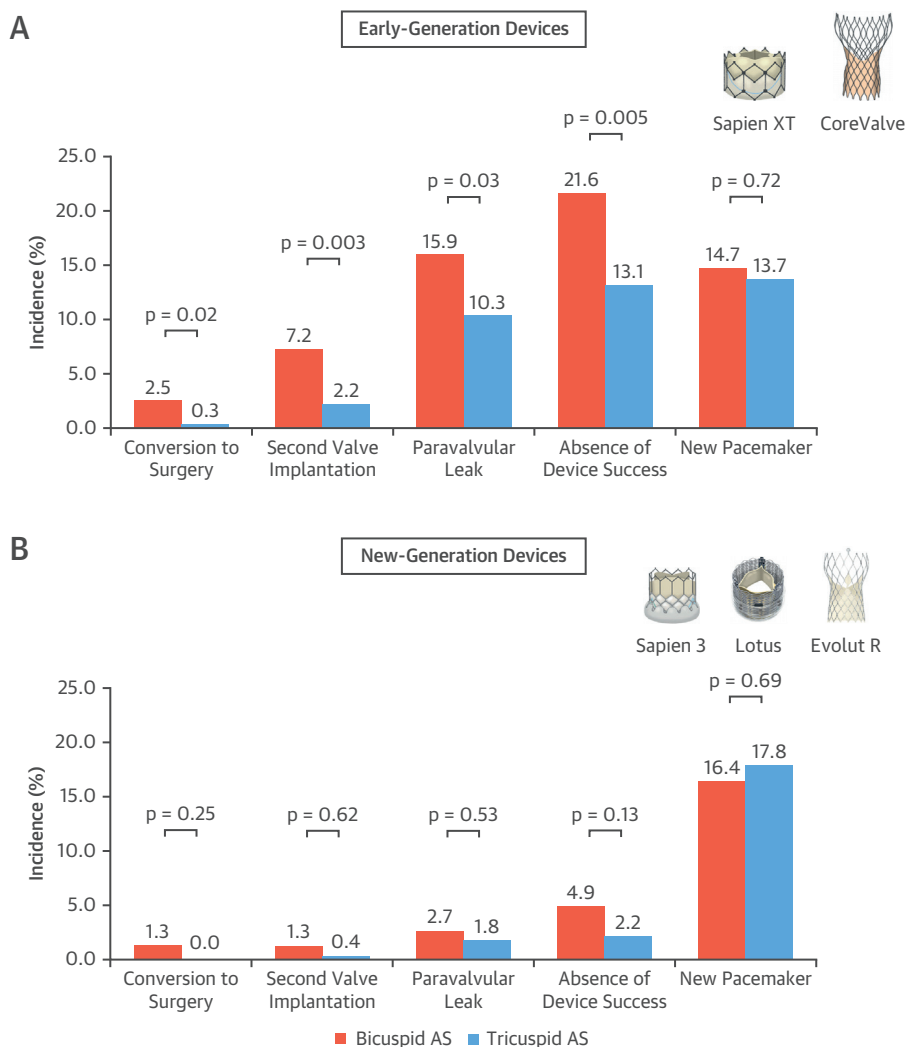
**Midterm mortality.** Over a median follow-up period of 460 days (IQR: 90 to 710 days), 66 patients died in the bicuspid AS group and 73 patients died in the tricuspid AS group. There were no differences between the 2 groups in cumulative event rates for all-cause mortality at the 2-year follow-up (17.2% vs. 19.4%;  $p = 0.28$ ) (Central Illustration). Furthermore, there were no significant differences in 1-year all-cause mortality rates between groups with stratification according to early- and new-generation devices (early-generation devices: 14.5% vs. 13.7%; log-rank  $p = 0.80$ ; new-generation devices: 4.5% vs. 7.4%; log-rank  $p = 0.64$ ) (Figures 3A and 3B). These findings were consistently observed in propensity score-matched cohorts for early- and new-generation devices (Online Figures 6A and 6B).

**DISCUSSION**

The present study is the first large-scale study to compare the safety, efficacy, and clinical outcomes of TAVR in patients with bicuspid and tricuspid AS. The major findings of the present study are as follows:

1. In the propensity score-matched cohort, TAVR in patients with bicuspid AS was associated with more frequent adverse procedural events compared with those with tricuspid AS. These differences were observed among patients treated with the early-generation devices.

**FIGURE 2** Procedural Outcomes in Bicuspid and Tricuspid AS With Early- and New-Generation Devices



Rates of conversion to surgery, second valve implantation, moderate or severe paravalvular leak, absence of device success, and new permanent pacemaker insertion after TAVR using (A) early-generation devices (Sapien XT/CoreValve) and (B) new-generation devices (Sapien 3/Lotus/Evolut R). Abbreviations as in Figure 1.

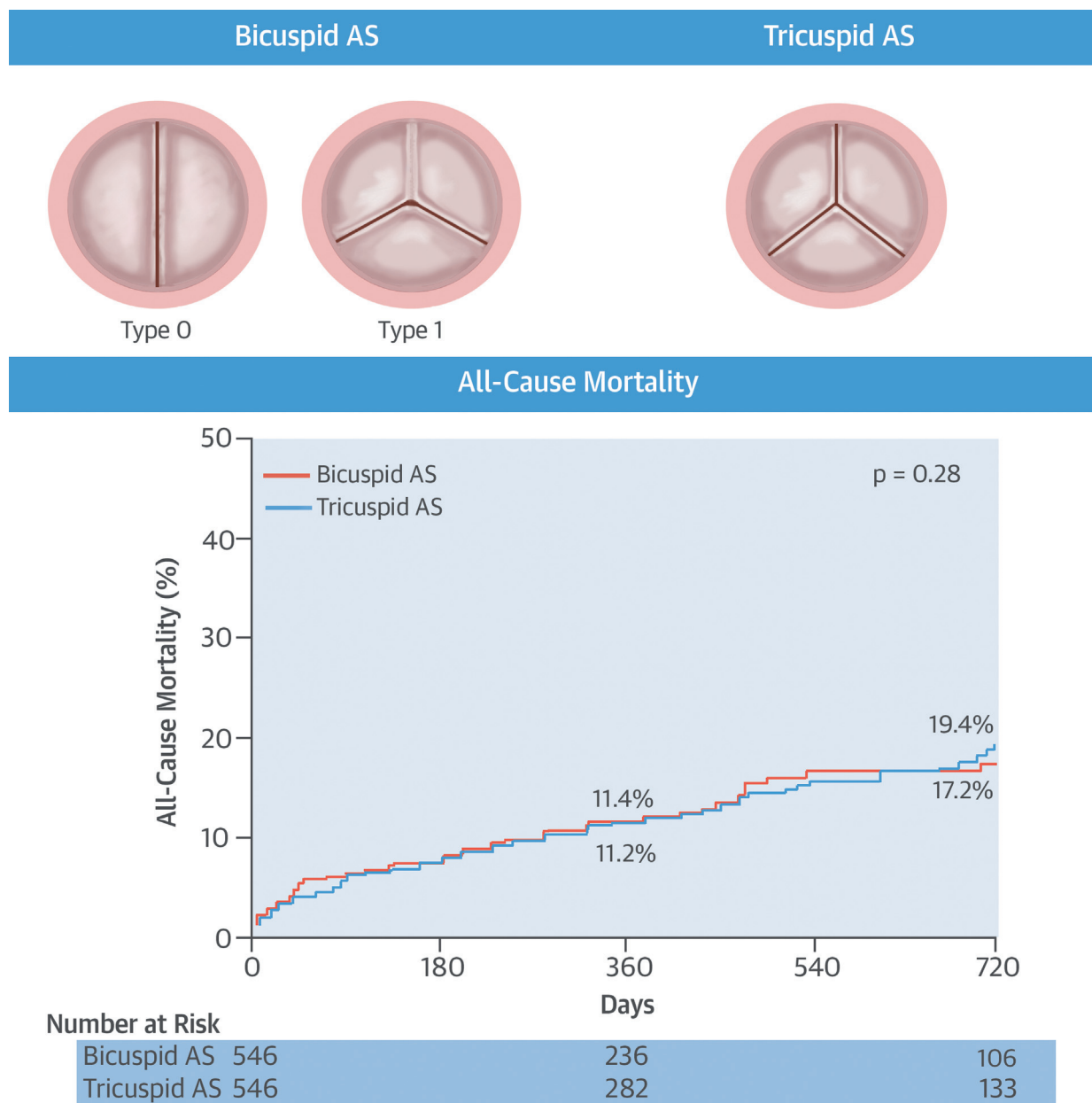
- However, there were no significant differences in procedural complications between groups when using the new-generation devices.
- The cumulative event rates for all-cause mortality at 2-year follow-up were comparable between the bicuspid and tricuspid groups.

Recently, 2 multicenter studies demonstrated the acceptable clinical outcomes of TAVR for bicuspid AS (8,10). However, patients included in those studies were younger and had less comorbidities compared with most published trials and observational studies including patients with tricuspid AS. Given that

patients with bicuspid AS have less coexisting comorbidities compared with patients with tricuspid AS, there is a potential risk that clinical outcomes of TAVR for bicuspid AS could differ from those for tricuspid AS with equivalent surgical risk. In the present study, patients with bicuspid AS in the crude cohort were younger and had less comorbidity than those with tricuspid AS. Both the bicuspid and tricuspid AS groups had an intermediate-risk profile, with mean logistic EuroSCOREs of 14.8% and 16.7%, and mean STS scores of 5.0% and 6.5%, respectively. In the present study, compared with tricuspid AS, TAVR in bicuspid AS was associated with similar



**CENTRAL ILLUSTRATION** TAVR for Bicuspid Versus Tricuspid Aortic Valve Stenosis



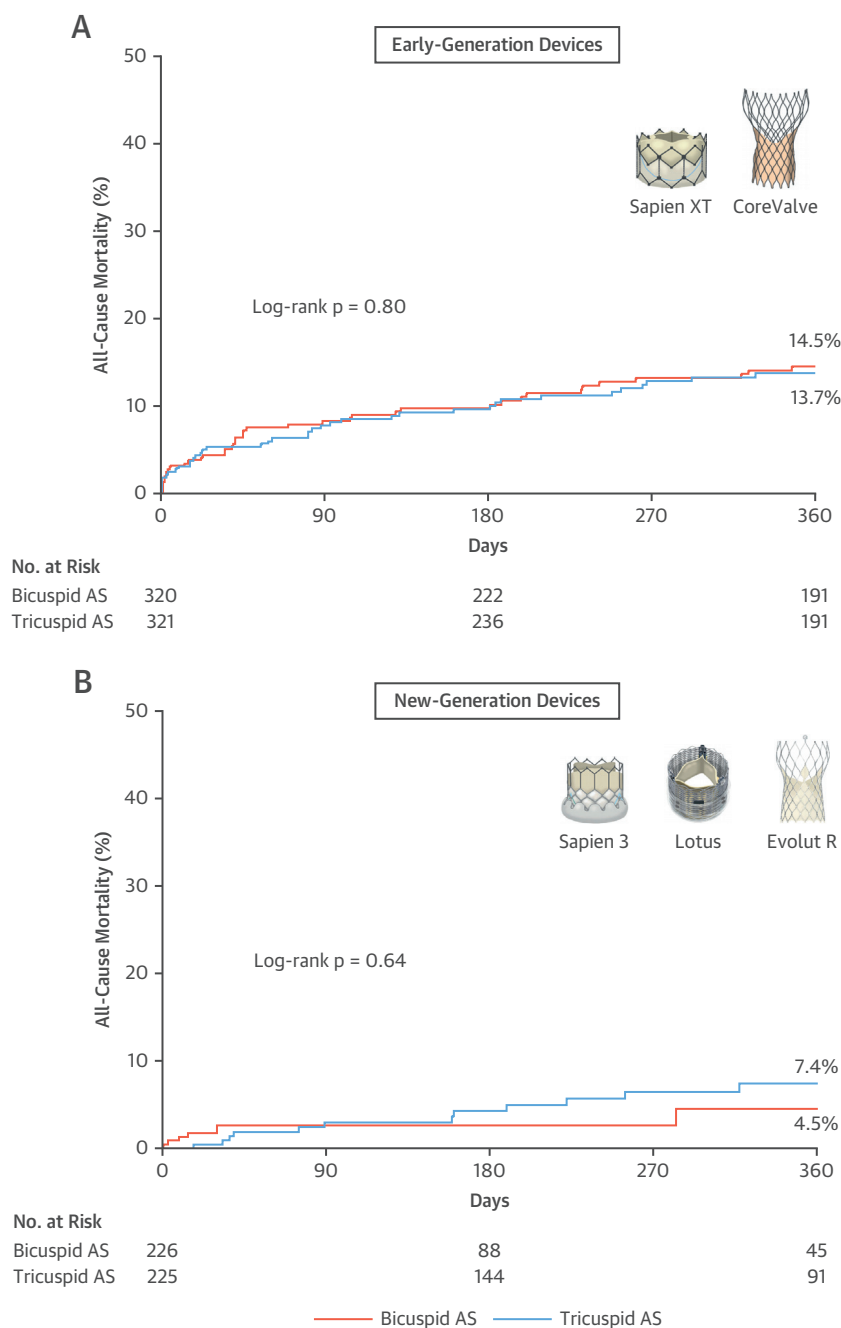
Yoon, S.-H. et al. *J Am Coll Cardiol.* 2017;69(21):2579-89.

**(Top)** Schematic presentations of bicuspid and tricuspid aortic valves. Type 0 and 1 indicate bicuspid aortic valve with no raphe, and 1 raphe, respectively. **(Bottom)** Cumulative all-cause mortality rates in patients with bicuspid AS (**orange**) and tricuspid AS (**blue**) in a propensity score matched cohort. Event rates were compared using the win ratio test. AS = aortic valve stenosis.

prognosis, although the device success was lower. The accumulation of a large multicenter database has, for the first time, allowed comparisons of matched cohorts, as well as the potential effect of differences in device type.

The present study also showed that procedural challenges of TAVR in bicuspid AS and related outcomes differed according to early- and new-generation devices. Within the group receiving the early-generation devices, patients with bicuspid

**FIGURE 3** Kaplan-Meier Curves for All-Cause Mortality According to Early- and New-Generation Devices



Cumulative all-cause mortality rates in patients with bicuspid AS (orange) and tricuspid AS (blue) treated with (A) early- and (B) new-generation devices, respectively. Event rates were compared using the log-rank test.

AS had more frequent aortic root injury, mainly related to Sapien XT implantation, and second valve implantation and moderate or severe paravalvular leak, mainly related to CoreValve implantation.

Among those treated with the new-generation devices, however, there were no significant differences in procedural outcomes between the bicuspid and tricuspid groups. The new-generation devices were

developed to mitigate the critical limitations of the early-generation devices: significant paravalvular leak, difficulty with optimal positioning, and vascular complications. All of these adverse events were reported to be associated with worse outcomes (26–29). The new-generation balloon-expandable Sapien 3, with an external sealing cuff allowing for effective sealing, eliminates the extreme oversizing and mitigates the morphological challenges of bicuspid AS. Similarly, the mechanical expanding Lotus valve, with an outer adaptive seal, as well as retrievability and repositioning capacity, may ameliorate the difficulties in optimal positioning and prevent paravalvular leak. The present study showed that the initial attempt of device advancement succeeded in overcoming the procedural limitations in tricuspid AS, and now goes beyond the challenges of treating bicuspid AS.

Given that a recent randomized trial demonstrated similar survival rates between TAVR and surgery in intermediate-risk patients (6), the extension of TAVR may be considered for younger and lower-risk patients with a possibly increased proportion of bicuspid AS. Despite procedural challenges of TAVR in bicuspid AS, the present study showed similar overall mortality rates between the bicuspid and tricuspid AS groups. This suggests that long-term mortality of patients with bicuspid AS is determined by multiple factors that also affect the prognosis of the tricuspid AS population.

Several essential factors should be considered in treating patients with bicuspid AS. Sievers et al. (30) showed a similar late survival and freedom from reoperation after surgery between the different types of bicuspid aortic valves. However, given the nature of transcatheter heart valves, future studies should evaluate the association between the types of bicuspid aortic valves and outcomes after TAVR. Furthermore, management of concomitant aortopathy in treating patients with bicuspid aortic valve should be taken into account. The risk of aortic rupture or dissection is greater in patients with a bicuspid aortic valve than in the general population (31), and also increases owing to aging-related progressive aortic dilation and degeneration (32). Given the expanding indication of TAVR for younger and lower-risk patients, physicians will face this dilemma in treating relatively younger patients with bicuspid AS and concomitant aortopathy. Several factors, including age, comorbidities, and additional risk factors for aortic complications, must be considered

during the decision-making process to treat patients with bicuspid aortic valve and concomitant aortopathy (33). Nevertheless, longer life expectancy in those patient populations mandates future studies to evaluate the effect of concomitant aortopathy, as well as valve durability for long-term follow-up.

**STUDY LIMITATIONS.** First, this study had the inherent limitations of an observational study without center-independent adjunction of adverse events and an independent core laboratory to diagnose bicuspid AS and assess paravalvular leak. Moreover, although propensity score matching is a well-accepted approach in observational research to address differences in baseline characteristics, it cannot account for unmeasured bias. Last, device selection was not randomized, but was at the operator's discretion, and patient selection as well as operator experience may have affected the observed outcomes.

## CONCLUSIONS

Compared with tricuspid AS, TAVR in bicuspid AS was associated with a similar prognosis, but a lower device success rate. Procedural differences were observed in patients treated with the early-generation devices, whereas no differences were observed with the new-generation devices.

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## PERSPECTIVES

### COMPETENCY IN PATIENT CARE AND

**PROCEDURAL SKILLS:** Compared with those with tricuspid AS, patients with bicuspid valves undergoing TAVR with early-generation devices more often developed adverse procedural events, but there were no significant differences between groups in procedural complications with newer-generation devices. Cumulative all-cause mortality at 2-year follow-up was comparable between the bicuspid and tricuspid groups.

**TRANSLATIONAL OUTLOOK:** Larger studies are needed to evaluate the long-term outcomes and durability of TAVR in patients with bicuspid AS.

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**KEY WORDS** aortic stenosis, bicuspid aortic valve, transcatheter aortic valve implantation

**APPENDIX** For a supplemental table and figures, please see the online version of this article.